CHARACTERISATION OF WATER CHESTNUT (ELEOCHARIS DULCIS) MICROFIBER AND E GLASS/POLYESTER HYBRID COMPOSITES

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Characterisation of Water Chestnut (*Eleocharis Dulcis*) Microfiber and E Glass/Polyester Hybrid Composites

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Abstract. *The purpose of this work is to investigate the physical and mechanical properties of hybrid composite made from water chestnut microfiber and e-glass within a polyester matrix. Water chestnut microfiber was produced through a delignification process by soaking the fiber in a 2% $KMnO_4$ solution, then proceeding with the cellulose isolation process using chemical treatments such as bleaching, acid hydrolysis, and ultrasonication mechanical treatment.*

The size of the water chestnut microfiber produced was in the range of 2.18 – 4.20 μm. The composite was made using the compression molding method at a pressure of 2 MPa and a temperature of 25 °C. The resulting hybrid composites were characterised. The lowest density yielded was 1.21 g/cm^3, while the highest MoR, MoE and tensile strength were 68.34 MPa; 4.99 GPa and 13.61 MPa, respectively. The hybrid composites of water chestnut microfiber and e-Glass at 15% volume fraction has the closest ideal characteristic value which has a tensile strength of 13.61 MPa, modulus of elasticity (MoE) of 3.99 GPa and a density of 1.45 g/cm^3.

Keywords: *hybrid composite, water chestnut microfiber, e-glass, MoE, MoR.*

I. Introduction

The use of natural fibers as reinforcing materials continues to grow. This is because natural fibers have a low density, are biodegradable, easy to recycle, and can be renewed [1]. Water chestnut is a local biomass in South Kalimantan Province that has the potential as a source of natural fiber. The area is ± 713 Ha, including grey sedge (*Lepironia articulata*) ± 641 Ha and water chestnut ± 72 Ha [2]. Based on the SPOT-6 image in 2019 which has an accuracy of 97.31% and a Kappa index of 0.92, water chestnuts in HSU district have an area of 24,903.22 ha [3]. Research on local biomass, including water chestnut, is one of Lambung Mangkurat University's vision to increase the value of local materials.

At this time the water chestnut (*Eleocharis dulcis*) has been used to make mats for the local community [4]. The potential of water chestnut is expected to be better utilized. The mechanical properties of water chestnut have been tested by Haryanti & Wardhana (2016) [5]. The bottom part of the water chestnut with a diameter of 2.158 mm has a tensile strength of 3.63 MPa and a tensile strength at the top with a diameter of 2.064 mm was 4.21 MPa. Several studies have used water chestnut as a biofilter [6], heavy metal absorber [4], activated carbon [7], and cement board composite material [8,9].

As reinforcement in composites, microfiber from natural fibers has many advantages such as low density, renewability, biodegradability, and relatively reactive surface. Microfiber can be made from natural fibers by isolating cellulose through delignification and ultrasonication processes. Ultrasonic treatment of cellulose reduces porosity, increases fiber dispersion in the matrix, as well as adhesion between matrix and fiber resulting in high tensile strength [10–12].

Alkali treatment is the most common and best method for fibers to be used to strengthen thermoplastic polymers and thermosets. The alkali treatment given can reduce the size of the fiber and increase the adhesive properties or interfacial adhesion of the elements present in the composite so as to increase the tensile strength of the composite. Smaller fibers will expand the contact between the surfaces and can improve the mechanical properties. Alkalis that are often used in natural fiber research are NaOH, KOH, LiOH, NaCl, and $KMnO_4$ [13–15]. The alkaline treatment of 2% $KMnO_4$ was able to reduce the size of the water chestnut fiber and reduce the levels of lignin, cellulose and hemicellulose [16–20].

Efforts to improve the mechanical properties of natural fiber-reinforced composites are not only treated with fibers, but also hybridized using synthetic fibers. The hybrid composite design uses bamboo fiber and woven e-glass fiber with polyester resin, exhibiting excellent interfacial bonding. Polyester resins are more often used for natural fiber types, in addition to being cheaper and can bind to natural fibers without causing reactions and gases. E-glass is a type of glass fiber with a low concentration of alkali glass, widely used because of its affordable price. E-Glass fiber is widely used in automotive industries such as in vehicle body panels. Glass-polyester composites are applied to ship hulls and aircraft parts [21–23]. This is a consideration to make a hybrid composite of water chestnut microfiber fiber with synthetic e-glass and polyester fibers to get a composite with good mechanical properties, and on the other hand it also saves costs.

The characteristics of hybrid composites are determined by the composition of the mixture between the matrix and the reinforcement. Water chestnut fiber as a reinforcement greatly determines the properties of the composite because it transmits the load distributed by the matrix. Water chestnut fiber in the form of microfiber is expected to produce optimal physical and mechanical properties of hybrid composites. The purpose of this study was to obtain the physical and mechanical properties of a hybrid composite made from microfiber, water chestnut fiber and e-glass with a polyester matrix. Water chestnut microfiber was produced through a delignification process by soaking the fiber in a 2% $KMnO_4$ solution, then proceeding with the cellulose isolation process using chemical treatments such as bleaching, acid hydrolysis, and ultrasonication mechanical treatment. The expected benefit is that water chestnut can be used as microfibers in the manufacture of hybrid composites and the use of the resulting composite products as candidates for drone frames. To take pictures or record images, drones are more cost and time efficient when compared to helicopters or satellites.

II. Research Methods

This research is a continuation of previous research [20]. Water chestnut (*Eleocaris dulcis*) used came from the location of the campus environment of the University of Lambung Mangkurat Banjarmasin in a wetland area. Water chestnut with a length of 100-160 cm were cleaned and dried for 2 x 8 hours. For the manufacture of fiber, water chestnut is cut to a maximum length of 2 cm, and then blended into thin shavings. After that, the water chestnut fiber was washed with water with stirring and heating at 80°C for 1 hour, then washed again with cold water.

Before being used as a composite material, water chestnut (*Eleocharis dulcis*) fibers were modified to micro size. The method used is the delignification method to reduce the lignin content, and the cellulose isolation method into microfiber. The delignification method was carried out by soaking the fibers in a 2% $KMnO_4$ solution. The cellulose isolation process was carried out using chemical treatments such as bleaching, acid hydrolysis, and ultrasonication mechanical treatment.

Modification of water chestnut fibers to become microfibers is expected to obtain a small fiber diameter. By using a small fiber diameter, the tensile strength of the composite would increase [24]. In this study, the size of water chestnut microfiber fibers produced by 2% $KMnO_4$ treatment in the range of 2.18 – 4.20 µm [20].

The composite matrix used in this research is Yukalac 157 BTQN-EX polyester resin with MEKPO (Methyl Ethyl Ketone Peroxide) catalyst (hardener). This resin is often used in composite manufacturing research. The ratio of polyester resin and MEKPO catalyst was 2:1. The function of the MEKPO catalyst is to accelerate the resin hardening process in the composite. Meanwhile, the synthetic fiber used is E-glass fiber in the form of a random chopped strand mat (CSM). The most widely used type of glass fiber in the industry is e-glass in the form of a random chopped strand mat (CSM) and woven roving.

Hybrid composite design made with variations in volume fraction composition. Water chestnut microfiber and e-glass used as reinforcement and polyester as a composite matrix. Variations in volume fraction composition of water chestnut microfiber, e-glass and polyester were 15%:15%:70%; 20%:20%:60%; and 25%:25%:50%. The composite was made using the compression molding method at a pressure of 2 MPa and a temperature of 25 °C. The composite is left for 1 – 2 days to dry and then removed from the mold.

The size of the mold used is 165 mm × 20 mm × 5 mm (radius of fillet: 76 mm) for the tensile strength test according to ASTM D638-14, then 120 mm × 25 mm × 5 mm for the bending test according to ASTM D790-92, and 20 mm × 20 mm × 5 mm for density testing. Then observed the effect of variations in volume fraction composition of water chestnut microfiber mixture, e-glass fiber with polyester on the physical (density) and mechanical strength (tensile strength, Modulus of Elasticity or MoE, Modulus of Rupture or MoR) hybrid composites and their surface morphology using SEM.

III. Results and Discussion

Composite materials generally consist of a matrix and reinforcement. The matrix is a material in the composite which has a dominant volume fraction which functions to transfer stresses to the fibers, form a coherent bond between the matrix/fiber surfaces, protect and separate the fibers, release the bonds and remain stable after the manufacturing process. While one of the main parts of the composite is the reinforcement which serves as the main load bearer on the composite [25,26].

The most basic drawback of natural fiber composites is the lack of good bonding between the matrix and fiber, resulting in poor composite properties. This deficiency is caused by the natural nature of natural fibers which can still absorb water so that water can enter the bond between the matrix and the fiber which ultimately affects the physical and mechanical properties of a composite. In the use of this water chestnut microfiber, chemical treatment by delignification in a 2% $KMnO_4$ solution followed by bleaching, acid hydrolysis, and proper ultrasonication mechanical treatment is expected to increase the bond between the fiber and the matrix, so that the composite properties become better.

The properties of polyester resin as a matrix with the brand Yukalac 157 BTQN-EX and synthetic fiber E-glass CSM as reinforcement used in this study can be seen in Tables 1 and 2.

Table 1. Polyester Resin (Yukalac 157 BTQN-EX) Properties [25,27]

Properties	**Value**
Density (kg/mm^2)	1.215 (1.217 g/cm^3)
Heat distortion temperature (°C)	70
Tensile strength (kg/mm^2)	5.5 (24.4 MPa)
Modulus of elasticity (kg/mm^2)	300 (0.36 GPa)
Elongasi (%)	1.6

Table 2. CSM E-Glass Fiber Properties [28,29]

Density (kg/m^3)	2550 (2.55 g/cm^3)
Tensile strength (N/mm^2)	3450 (2400 MPa)
Young's modulus (GPa)	75 (73 GPa)
Poisson ratio	0.27
Elongation (%)	2.5 (3)
Linear thermal expansion (m/m/°C)	32×10^{-6}
Thermal conductivity coefficient (W/m °C)	3.0

Physical and mechanical properties testing of hybrid composites was carried out with three specimen variables, namely specimens with codes B, C and D. Test specimen B was a test object with a volume fraction composition of Microfiber: E-glass: Polyester = 25%: 25%: 50%, Test specimen C is test object with volume fraction composition variation Microfiber: E-glass: Polyester = 20%: 20%: 60%, Specimen D is test object with volume fraction composition variation Microfiber: E-glass: Polyester = 15%: 15 %: 70%. Specimens B, C and D have an average thickness of 6.44; 6.17; and 6.54 mm, respectively.

(a) (b) (c)

Figure 1. Hybrid composite samples

(a) Hybrid Composite (B) microfiber volume fraction composition: e-glass: polyester = 25%:25%:50% (tensile test specimen).
(b) Hybrid Composite (C) composition of microfiber volume fraction: e-glass: polyester = 20%:20%:60% (bending test specimen).
(c) Hybrid Composite (D) composition of microfiber volume fraction: e-glass: polyester = 15%:15%:70% (tensile test specimen).

The physical (density) and mechanical characteristics (tensile strength, MoE and MoR) of water chestnut, e-glass and polyester microfiber hybrid composites are shown in the following discussion.

1.1 Hybrid Composite Density

Density testing is a test of the physical properties of the specimen, which aims to determine the mass density value of the specimen being tested.

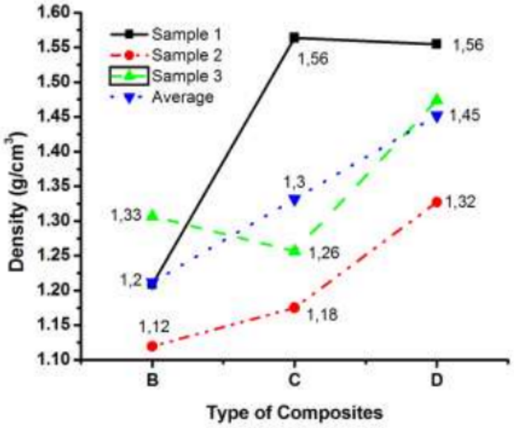


Figure 2. The Density of Hybrid Composites

In this study, the average density of the hybrid composite was obtained between 1.21 g/cm^3 - 1.45 g/cm^3. The lowest mean density was hybrid B composite with 25% volume fraction of water chestnut microfiber and the highest average density was hybrid composite D with 15% water chestnut microfiber volume fraction.

In Figure 2, it appears that the volume fraction composition of water chestnut microfiber of 25% (1.21 g/cm^3) has a lower average density of hybrid composites than the volume fraction of water chestnut microfiber 20% (1.33 g/cm^3) and volume fraction of water chestnut microfiber of 15% (1.45 g/cm^3). The average density of the composite with the volume fraction of water chestnut microfiber fiber and 30% e-glass fiber (hybrid composite D) was higher than the average density of the composite with the volume fraction of water chestnut microfiber and 40% e-glass fiber (hybrid composite C) and the average density composite with volume fraction of water chestnut microfiber and 50% e-glass fiber (hybrid composite B). The increase in composite density is in accordance with the use of volume fractions of polyester and e-glass fiber which have a higher density of 1,215 kg/mm^3 or 1.215 g/cm^3 and 2,550 kg/m^3 or 2.55 g/cm^3 [18,27–29].

The addition of water chestnut microfiber as reinforcement can cause a decrease in the density of the hybrid composite. In Figure 2, it can be seen that the average density of the hybrid composite with a higher volume composition of water chestnut microfiber is relatively lighter than the hybrid composite with a lower volume composition of water chestnut microfiber. Based on SNI 01-4449-2006, hybrid fiber composites are classified as high density fiberboard. The density of a drone in use today is 1.10 – 7.80 g/cm^3 (Perdana et al, 2018). So it can be recommended that the density of the hybrid composite as a result of this study using water chestnut microfiber is feasible to be used as a building material for the drone frame.

3.2 Hybrid Composite Tensile Strength

The tensile strength (tensile strength or ultimate tensile strength) shows the ability of the composite to accept stress without causing the composite to be damaged or broken. Some materials are brittle or brittle, meaning they can simply break without deforming. Other materials will stretch and deform before fracture, which is called an elastic material (ductile). Tensile strength is obtained by performing tensile tests and recording changes in strain and stress. The highest point of the stress-strain curve is called the ultimate tensile strength (UTS) [26,30].

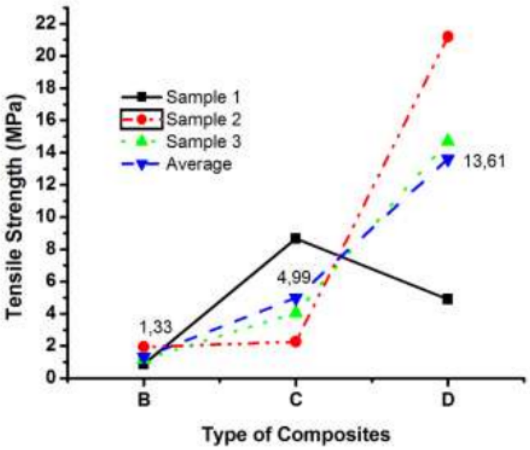


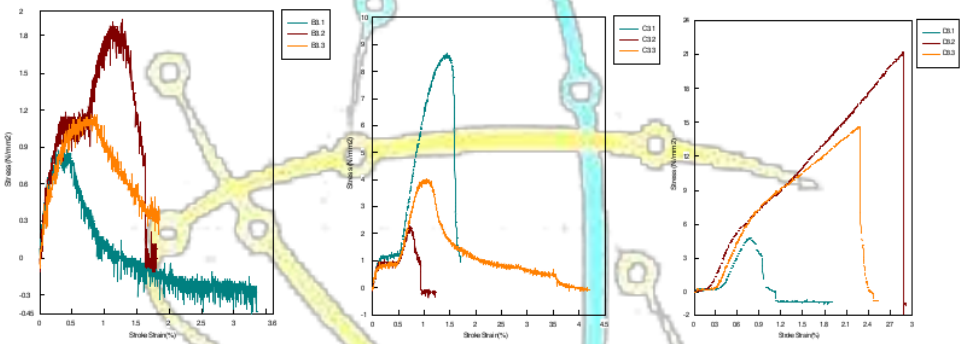
Figure 3. The Tensile Strength of Hybrid Composites

In this study, the average tensile strength of hybrid composites ranged from 1.33 MPa to 13.61 MPa. From Figure 3, it is found that in the volume fraction of 15% (D) water chestnut microfiber reinforcement (D), the composite with the highest tensile strength is 13.61 MPa. Meanwhile, the lowest composite tensile strength was in the volume fraction of 25% (B) water chestnut microfiber reinforcement (B) of 1.33 MPa. The tensile strength of the hybrid composite in each volume fraction of 15%, 20% and 25% water chestnut microfiber reinforcement was 13.61 MPa, 4.99 MPa and 1.33 MPa. The average maximum force applied to hybrid composites B, C and D are 105.21, 389.06, and 1124.48 N.

In Figure 3, the tensile strength of the hybrid composite with 50% microfiber and e-glass fiber volume fraction (B) is lower than the 40% microfiber and e-glass fiber volume fraction (C). The highest composite tensile strength was with the volume fraction of microfiber fiber and e-glass 30% (D). The tensile strength of the hybrid composite is also increasing due to the large tensile strength of polyester and e-glass fiber, as shown in Tables 1 and 2, which are 24.4 MPa and 2400 MPa [27,29]. From the results of the tensile strength of the hybrid composite, this result is not close to the tensile strength of the drone frame material with derlyn material, which is 52.40 MPa [31].

The low tensile strength of the composite is also caused by the emergence of voids (trapped air) in the mold or the imperfect bond between the fibers and the matrix, causing the fibers to separate from the matrix (debonding failure). The increase in tensile strength shows a change in the interface between the fiber as reinforcement and the matrix, because the strength of the composite is a combination of the strength of the matrix and reinforcement, so it will depend on the interface. The better the fiber-matrix bond, the tensile load given to the composite will be well distributed on the fiber, and vice versa if the fiber-matrix interface is not strong, the tensile load is only retained by the matrix, while the volume of the matrix has been reduced due to the addition of fiber. In other words, the strength of the composite lies only in the matrix.

The stress-strain curve of the tensile strength test of the hybrid composite is shown in Figure 4.



(a) (b) (c)

Figure 4. The Hybrid Composites Tensile Strength Stress-Strain Graph
(a) Hybrid Composite (B); microfiber: e-glass: polyester = 25%:25%:50%
(b) Hybrid Composite (C); *microfiber*: e-*glass:* polyester = 20%:20%:60%
(c) Hybrid Composite (D); *microfiber*: e-*glass:* polyester = 15%:15%:70%

From Figure 4, the stress-strain curve of the tensile strength of the composite shows that the hybrid composite deforms when it is given a load and it can be seen that as the volume fraction of water chestnut microfiber decreases, the composite tends to fracture immediately when it is subjected to a load. The difference in the shape of the image in the form of vibration on composite B is a difference in the plot on the reading scale of the test equipment at the time of deformation of the load applied to the composite specimen.

In Figure 4 (a) the stress-strain curve of the hybrid composite B, the specimen fractured with a force of 105.21 N and experienced an average stress of 1.33 MPa and an average strain of 0.82%, so that this hybrid composite is weak and brittle. Hybrid composite C specimen fractures after experiencing an average strain of 1.07% and an average stress of 4.99 MPa and a force of 389.06 N as shown in Figure 4 (b), the hybrid composite is more flexible and firm. In Figure 4 (c) hybrid composite D, the specimen breaks after experiencing a force of 1124.48 N, an average stress of 13.61 MPa and an average strain of 1.98%. This hybrid composite is firm and brittle.

Several possibilities that cause the decline in the strength of the composite include: (1). The presence of trapped air (voids) in the composite. This is due to the larger the volume fraction of fiber as reinforcement in the composite, the more voids contained in the composite. (2). The distribution of the fibers is not even, so the resulting composite strength is also uneven at each point. (3). Lack of strong bonds between the matrix as a binder with the fiber as reinforcement. This will cause debounding (release of bonds between the fiber and the matrix) [25,26].

Utilization of natural fiber galam wood shavings using polyester resin tested for its mechanical properties obtained optimum results at 70% fiber volume fraction with a tensile strength value of 13.07 MPa. While the hybrid composite uses polyester resin with hemp fiber and glass fiber materials, the result is a maximum tensile stress value at a mixture fraction of 50% resin, 30% glass fiber and 20% hemp fiber with a value of 36.687 GPa [32,33].

3.3 MoE (*Modulus of Elasticity*) and MoR (*Modulus of Rupture*) of Hybrid Composites

The modulus of elasticity is the value of a material's resistance to elastic deformation when a force is applied to the material. Materials with high stiffness when subjected to loads (within their elastic limits) will experience elastic deformation but only slightly. The stiffness of the material is usually indicated by the modulus of elasticity where the greater the modulus of elasticity of the composite, the stiffer the composite material.

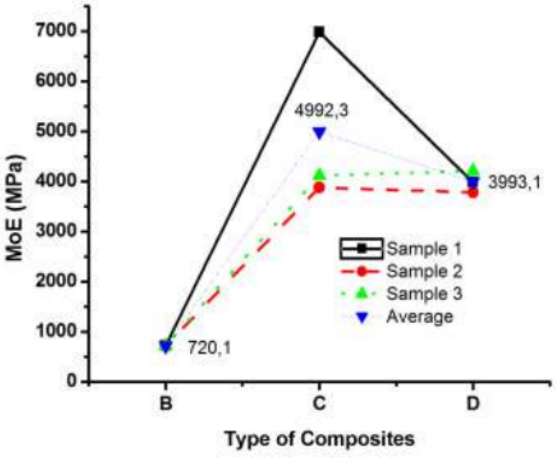


Figure 5. The MoE of Hybrid Composites

In this study, a hybrid composite material was obtained which has a modulus of elasticity in the range between 0.72 GPa - 4.99 GPa. The amount of increase in the length of an object when stretched is different from one another, depending on the elasticity of the material. The greater the modulus of elasticity of an object, the harder it will be for the material to elongate or shorten.

The elongation accuracy of the fiber-reinforced hybrid composite obtained after the tensile test also has an effect on the modulus of elasticity of the composite. The greater the composite elongation value, the greater the modulus of elasticity. Meanwhile, the highest modulus of elasticity is composite with volume fraction of water chestnut microfiber reinforcement and 40% e-glass (C) which is 4.99 GPa and the lowest is composite with volume fraction of water chestnut microfiber fiber reinforcement and e-Glass 50% (B) which is 0.72 GPa.

In Figure 5, the comparison graph of the MoE of the hybrid composite with water chestnut microfiber reinforcement and e-glass with a fiber volume fraction of 50% (B) has a lower MoE value than the hybrid composite with water chestnut microfiber reinforced and e-glass with a fiber volume fraction 40% (C) and 30% (D). While the hybrid composite reinforced with water chestnut microfiber and e-glass with a fiber volume fraction of 40% (C) had a higher MoE (4.99 GPa) than the hybrid composite with 30% fiber reinforcement (D), which was 3.99 GPa.

From the results of the modulus of elasticity of the three types of hybrid composites above, it should be directly proportional to the increase in the volume fraction of the reinforcement, voids are also one of the contributing factors. Meanwhile, as shown in Tables 1 and 2, the elastic modulus of polyester and e-glass fiber are 0.36 GPa and 73 GPa, respectively [27,29].

In general, from the graph of the relationship between the modulus of elasticity (GPa) and the volume fraction (%), it can be said that the value of the modulus of elasticity in hybrid composites of microfiber and e-glass fiber and polyester matrix with volume fraction variations is 50%, 60%, 70%, increased from the volume fraction of 50% to 60%, while from the volume fraction of 60% to 70%, it decreased significantly along with the addition of the mixed fiber.

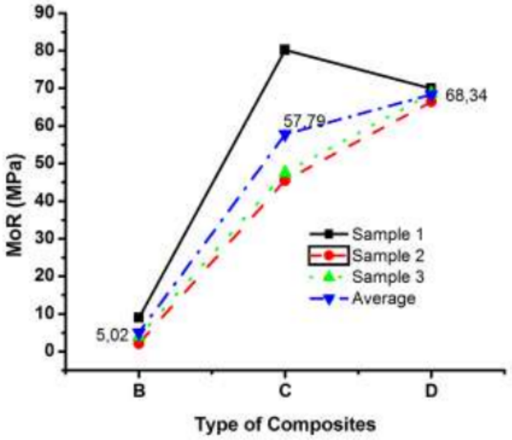


Figure 6. The MoR of Hybrid Composites

In this study, hybrid composite materials were obtained which had MoR in the range between 5.0150 GPa – 68.3434 GPa. In Figure 6, the comparison graph of the MoR of a hybrid composite reinforced with water chestnut microfiber and e-glass with a reinforcement volume fraction of 50% (B) has a lower MoR value than a hybrid composite with a reinforcement volume fraction of 40% (C) and 30% (D).).

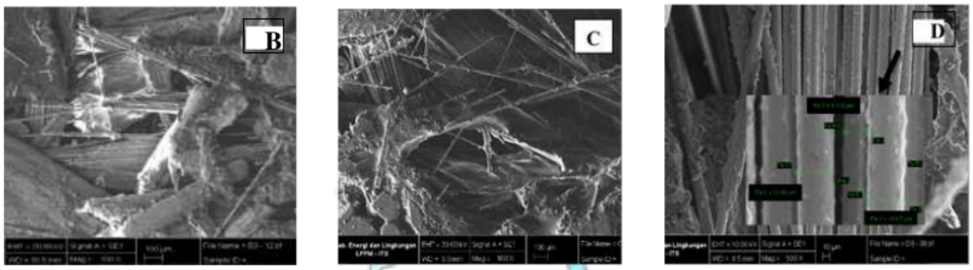
From Figure 6, the MoR value of the hybrid composite with the volume fraction of water chestnut microfiber reinforcement and e-glass with the highest value is composite D of 68.34 MPa. Meanwhile, the MoR value in the hybrid B composite is much lower than the composition of the other volume fractions, which is an average of 5.02 MPa. This is probably due to the weak bond between the water chestnut microfiber and the e-glass fiber to the polyester matrix. Lack of strong bonds between the matrixes as a binder with the fiber as reinforcement will cause debounding (release of bonds between the fiber and the matrix) [25,26].

The tensile strength of the leaf hybrid chip composite with e-glass and polyester matrix has an average stress of 18.50 MPa and a MoE of 13.75 MPa. While the use of bagasse fiber and $CaCO_3$ powder with a polyester matrix, the highest composite flexural strength was obtained at the 20:10 volume composite filler fraction, which was 59.76 MPa [34,35].

In general, the weakness of composites against bending loads lies in the composite portion which has not been evenly compressed between the fibers and the matrix at the bottom of the specimen. This layer has maximum tensile strength and will fail early because it is unable to withstand the tensile stress at the bottom of the composite, so cracking will occur early. The maximum load-bearing strength occurs in the composite parts inside, where there is a lot of mixing between the fibers and the matrix evenly. After the inside is unable to withstand the load, the lower part is unable to withstand the load, there will be cracks at the bottom of the specimen, and this is the initial crack in the composite. After the bottom is fractured, the load-bearing strength decreases drastically.

3.4 SEM of Hybrid Composites

The SEM test to determine the characterization of the surface morphology and cross-section of the hybrid composite was carried out using a composite sample that had been tested for its mechanical strength. The results of the composite SEM test can be seen in Figure 7.



(a) (b) (c)

Figure 7. SEM Results of Hybrid Composites

(a) Hybrid Composite B; *microfiber*: *e-glass:* polyester = 25%: 25%: 50%.
(b) Hybrid Composite C; *microfiber*: e-*glass:* polyester = 20%: 20%: 60%.
(c) Hybrid Composite D; *microfiber*: e-*glass:* polyester = 15%: 15%: 70%.

From the micro-observation, it can be seen that the damage was caused by the defective bond between the e-glass fiber and the microfiber of water chestnut with the polyester matrix. This could be caused by the matrix does not bind the fibers as a whole, so that what happens is that the fibers are released from their bonds with the matrix, so that cracks occur around the fibers that cause the bonds to be released.

The bond between e-glass fiber and water chestnut microfiber which is not strong causes the hybrid composite to be brittle and can be repaired by reducing the volume fraction of the reinforcement and adding the volume fraction of polyester as a matrix so that the composite is more easily fused. This can be seen in hybrid composites which are becoming more homogeneous as in hybrid composites D.

The SEM photo of the hybrid composite is a specimen after mechanical testing, so it can be seen that in the hybrid composite B and C the fibers have broken. Composite D looks almost no fracture in the fibers in the composite so it can be concluded that this composite is stronger, and can be seen in the composite mechanical test data. The voids that are clearly seen in hybrid composites B and C are more than hybrid composites D. From the SEM results, hybrid composites with a volume fraction composition of water chestnut microfiber and e-glass and polyester, namely 15% : 15% : 70% produce composites that are more dense and homogeneous.

From the description above, it is found that the hybrid composites that are close to ideal according to their physical and mechanical properties, which are strong, rigid and light, was at 15% reinforcement volume fraction. The hybrid composite reinforced with water chestnut microfiber and e-Glass fiber at 15% reinforcement volume fraction has the closest ideal characteristic value which has a tensile strength of 13.61 MPa, a modulus of elasticity of MoE of 3.99 GPa and a density of 1.45 g. /cm3. From the characteristics of the composites, especially from its density, it can be said that a hybrid composite material with water chestnut microfiber reinforcement and e-Glass fiber can be used as an alternative application to drones.

IV. Conclusions

Hybrid composite samples have been made with water chestnut microfiber reinforcement and e-Glass fiber with volume fractions of 15%, 20%, and 25%, respectively. Furthermore, the characterization of the composite material was carried out. The effect of fiber volume fraction on the characteristics of the composite samples did not show the trend it should have; this was due to the large number of voids in the composite samples.

It is found that less water chestnut microfiber added as reinforcement could cause a decrease in the density of the hybrid composite. Therefore, the lowest density of hybrid composites was at hybrid composites with a volume fraction of 25% water chestnut microfiber fiber, which yieled 1.21 g/cm^3. The tensile strength of the hybrid composite also tends to increase with the decrease of the water chestnut microfiber composition (high polyester volume fraction), the highest average tensile strength value was in the composition of microfiber water chestnut, e-glass and polyester (15%: 15%: 70%) which was 13.61 MPa. The highest MoE value of 4.99 GPa was yielded at the composite with the composition of water chestnut microfiber, e-glass and polyester 20%: 20%: 60%. While the highest MoR value of 68.34 MPa was yielded at the composition of microfiber, e-glass and polyester, 15%: 15%: 70%. The SEM image also showed more dense and homogeneous composite at composites of microfiber water chestnut, e-glass and polyester (15%: 15%: 70%). Therefore, the hybrid composites of water chestnut microfiber and e-Glass at 15% volume fraction was the closest ideal characteristic value which has a tensile strength of 13.61 MPa, modulus of elasticity (MoE) of 3.99 GPa and a density of 1.45 g/cm^3.

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